

Force or pressure sensor and method for applying the same

The invention relates to a force or pressure sensor, comprising a substantially rigid, mechanical-load resistant frame, a flexible diaphragm secured over its peripheral rim to the frame, and a piezoelectric sensor diaphragm applied to the surface of the flexible diaphragm.

The invention relates also to a method for applying this method, such that a sleeping or lying person can be measured for his or her heart rate and respiratory amplitude, as well as frequency.

Patent publications US-4,570,097, US-4,567,395, US-4,590,400 and US-5,353,633 disclose a piezoelectric pressure sensor for measuring changes of a cylinder pressure in an internal combustion engine during ignition. The cylinder pressure is supplied by means of a separate transmitter body to a piezoelement, which is subjected to compression according to a pressure change occurring in the engine cylinder. Since the piezocrystal is compressed and its surface area is relatively small, the sensor remains comparatively low in responsivity. The sensor is not structurally designed to provide simultaneously a high load rating and a high sensitivity.

Published application WO 99/47044 discloses a piezoelectric pressure sensor for measuring blood pressure changes in a blood vessel. The pulse of a blood vessel is delivered by means of a transmitter diaphragm and a rod to a piezoelement, which is subjected to deflection according to a pressure change occurring in the blood vessel. Since the load is received by a sensitive transmitter diaphragm, the sensor has a remarkably low static resistance to pressure. In addition, the sensor's piezoelement is structurally asymmetrical.

Patent publication US-5,365,937 describes a piezoelectric sensor for measuring cardiomuscular rate on skin surface. Some of the sensor's housing

structure consists of a piezoelement. Since some of the sensor's housing structure consists of a piezoelement, the sensor's static resistance to pressure is relatively modest. The movement applied to a piezoelement in the sensor is transmitted over the entire surface area of the piezoelement.

Patent publication US-4,803,671 discloses a sensor for acoustic pressure wave pulses, wherein a piezoelectric measuring diaphragm is disposed in a space between two coupling diaphragms filled with a coupling medium. This sensor is not capable of handling major external loads, either.

It is an object of the invention to provide a force or pressure sensor, which is highly capable of handling major external loads, yet at the same time is extremely responsive even to very slight changes in force or pressure.

This object is achieved by a force or pressure sensor of the invention, which is provided with the characterizing features set forth in the appended claim 1. The dependent claims disclose preferred structural solutions of the invention, which assist in reaching the above objective.

By virtue of the features of a sensor of the invention, i.e. a high load rating and responsivity, it can be applied with particular benefits in a method, by which a sleeping or lying person is measured for his or her heart rate and respiratory amplitude, as well as frequency. The features characteristic of the method are set forth in the appended claim 12. Implementing options for the method are set forth in claims 13 and 14.

The inventive force or pressure sensor and its application will now be described in more detail with reference to the accompanying drawings, in which

- Fig. 1 shows a force or pressure sensor of the invention in a sectional view,
- Fig. 2 shows a variant for the sensor of fig. 1, which can be used for measuring changes in fluid or gas pressure,
- Fig. 3 depicts a sensor application method for measuring a sleeping or lying person for his or her heart rate and respiratory amplitude, as well as frequency, and
- Fig. 4 shows a method otherwise similar to fig. 3 except for an alternative disposition of the sensor.

The sensor to be described hereinafter has properties like a high resistance to force or pressure, a high sensitivity, a trouble-free operation, a simplicity of required electronics, and a broad frequency repetition. Surprisingly, all these qualities are achieved with a sensor assembly to be described hereinbelow.

A sensor frame 1 is substantially rigid and resistant to mechanical loading. Therefore, the frame 1 is made e.g. from stainless steel. A sensor cover 4 is also substantially rigid and resistant to mechanical loading, and preferably made from stainless steel or another suitable metal. The frame 1 and the cover 4 are metal blocks in the shape of bodies of revolution. They can also be made of a plastic or composite material or some other rigid, durable material. The actual sensor element comprises a piezoelectric ceramic diaphragm 3, which is applied to a thin, flexible metal diaphragm 2. The flexible metal diaphragm is in turn attached by its peripheral rim between the frame 1 and the cover 2. The frame 1 and the cover 2 define therebetween a closed, hermetically sealed housing chamber, the flexible diaphragm 2 and the sensor diaphragm 3 being located thereinside.

In terms of its diameter, the piezoceramic sensor diaphragm 3 is smaller than the metal diaphragm 2, which is why the sensor diaphragm 3 has its peripheral rims left at a distance from the inner periphery of the housing chamber. Such combination of a metal diaphragm and a piezoceramic sensor diaphragm is prior known and generally used in piezoelectric loudspeakers for producing sound by conducting an electric signal to the diaphragm. Such a piezoelectric loudspeaker is prior known e.g. from patent publication US-2002/0067840A1.

The cover 4, functioning as a loading element, is provided with a protrusion or shoulder 4a, bearing against the flexible diaphragm 2 in its mid-section, and hence prestressing the flexible diaphragm 2 and the sensor diaphragm 3 attached thereto. A sensor-signal transmitting contact spring 5 is in contact with the sensor diaphragm 3 opposite to the cover protrusion 4a. The frame 1, the cover 4, and the diaphragms 2 and 3 are all rotationally symmetrical with respect to the cover protrusion or shoulder 4a. Despite the fact that the cover has a load rating or load carrying capacity which is very high, typically more than 50 kg and preferably more than 100 kg, the sensor has an extremely high responsivity to changes in a force  $F$  or a pressure  $p$ . It has been discovered in practical experiments that the sensor provides a clear and highly decipherable output signal as the change of a load applied to the cover 4 is less than  $10^{-6}$ , even less than  $10^{-9}$  x load rating of the cover 4. In this conjunction, the load rating of the cover refers to its elastic loading section, over which the sensor retains its functionality and high responsivity.

An amplifier 6 and its circuit board 7 are located within the housing chamber defined by the frame 1 and the cover 4. The amplifier 6 has its input impedance matched to provide a desired settling time, during which the amplifier's 6 output sets essentially to zero as the loading applied to the cover 4 remains unchanged. Thus, the input impedance of the amplifier 6 is used for making the sensor applicable to various applications, in which the

measured fluctuation of force or pressure can happen at a low or a high frequency. The sensor's output cable 8, extending from the amplifier 6, comprises a single- or multi-wire screened cable.

Fig. 2 differs from the embodiment of fig. 1 in that the cover 4 has its threaded sleeve 9 fitted with an adapter element 10, 11, by way of which the cover 4 can be loaded with changes in a fluid or gas pressure. The member 10 defines a pressure chamber, and the member 11 is e.g. a threaded fitting piece.

In the embodiment of fig. 1, the cover 4 is also provided in the middle with an upward protrusion 4b, which is subjected to mechanical loading. The cover plate 4 has a thickness between a curb collar 4c and the central protrusions 4a, 4b in the order of e.g. 1 mm, and the sensor diameter can be in the order of 2-3 mm.

The sensor's operation is based on the fact that, as a compressive force is applied to the protruding part 4b in the mid-section of the cover plate 4, the cover element 4 depresses slightly inward and deflects the piezo-diaphragm 3 with its protrusion 4a. The deflection of the cover element 4 must be very slight indeed, as the ceramic piezo-diaphragm 3 is easily ruptured. Upon deflection, the piezo-diaphragm 3 generates a potential, which is conducted by way of the contact spring 5 to the high-impedance amplifier 6. The amplifier 6 turns the output impedance lower, thus improving the output signal's immunity to interference.

The application of a sensor of the invention will now be described in connection with a method, whereby a sleeping or lying person is measured for his or her heart rate and respiratory amplitude, as well as frequency. In the method, a sleeping person can be measured, without having any wires or transducers connected to the person, for his or her heart rate and

respiration, regardless of a person's lying posture (on his or her back, side or belly). The method utilizes a ballisto-cardiographic signal generated by the heart and a weight change in a person at rest, resulting from pulmonary movements and strains. The measurement has been enabled by a sensor of the invention, which is concurrently provided with a high load rating and a high responsiveness.

Fig. 3 illustrates a first alternative of the method, wherein under the post or posts of a bed is placed a responsive sensor 13 as described above, identifying a change in force or pressure. As a person is lying, the sensor identifies, through the intermediary of a bed frame 16, a weight change caused by the heart as well as respiration. The signal processing is effected by using a filter 17 for the filter-separation of a higher-rate frequency component coming from the sensor 13, thereby enabling the measurement of a person's heart rate for its amplitude and frequency. An oscilloscope 18 is provided with a graph representative of cardiac function. By using a filter 19 for the filter-separation of a low frequency component coming from the sensor 3, it is possible to measure the amplitude as well as the frequency of human respiration, a graph representing the same being displayable on an oscilloscope 20. The oscilloscopes 18 and 20 are optionally replaceable with a plotter or an electronic memory, from which the graphs can be transferred onto a computer screen.

In the alternative of fig. 4, the sensor 13 is placed between a top mattress 14 and an actual mattress 15 in a bed 12 in line with the thorax of a person. The sensor 13 is prevented from sinking in the top mattress 14 and/or the actual mattress 15 by means of panels 21 and 22, which are more rigid than the mattresses and between which the sensor 13 is positioned. In the illustrated case, under the top mattress 14 lies a resilient panel 20, extending essentially across the width of the mattresses, and thereunder a rigid backing panel 22, whose surface area is confined within a section of the

upper body, such that the function of the actual mattress 15 is not substantially impeded. By using the panels 21, 22 of an appropriate surface area, it is possible to identify the heart rate, as well as respiration, reliably over a more extensive area (and, if desired, a change in the sleeping posture of a sleeping person during sleep). Hence, the comfort of a sleeping platform is not impaired by the sensor system.

The method can be used in monitoring or attending to heart patients, lung patients, demented patients, sleep apnea patients, a child's sleep, etc.

Other possible applications for a sensor of the invention include:

- Wearing of engine bearings (audibility range)
- Pressure changes in the combustion chamber of an engine cylinder
- Dynamic stress of bearing supports (measurement at low frequencies; stresses and torques applied to axles etc.)
- Wobbling of building structures (swaying of tall buildings and smokestack structures, e.g. as a result of wind action)
- As a seismographic sensor for controlling an earthquake alarm system (apartment-specific alarm like a fire alarm)
- As a surveillance device in buildings (capable of detecting depression of floor)
- Sensor can also be used for measuring a fluid or air pressure by modifying the cover plate design.